DEVELOPMENT OF STINGRAY ROBOT

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ABSTRACT

This project involves the design and construct of biological inspired underwater robot that mimicking the stingray maneuverability. The robot will be design based on the shape of stingray, and has the abilities to swim like a stingray. There were three major parts in constructing the robot; mechanical design, electronic circuitry and software design. In the mechanical part, body frame and fins is design carefully in order to make the movement of the robot smooth underwater. 4 servo motors and DC motors are used to move the robot forward and downward (submerge). Flapping motion is performed by the servos rotation controlled by the PIC18F4550 microcontroller.

ABSTRAK

Projek in melibatkan rekabentuk dan pembinaan robot berasaskan biologi yang menyerupai pergerakan ikan pari. Robot ini direkabentuk berasaskan bentuk dan mempunyai kebolehan untuk bergerak seperti ikan pari. Terdapat 3 bahagian penting dalam membina robot ini; rekabentuk mekanikal, rekabentuk elektronik dan rekabentuk perisian. Bagi bahagian mekanikal, binkai badan dan sirip direkabentuk dengan teliti bagi memastikan pergerakan robot lancer di dalam air. 4 motor servo dan motor DC digunakan bagi menggerakkan robot kehadapan dan ke bawah (menyelam). Gerakan mengepak di lakukan oleh kawalan pusingan motor servo oleh pengawalmikro PIC18F4550.

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CHAPTER 1

INTRODUCTION

1.1 Introduction

In the deep ocean live many types of fishes with their own features and expertise. Movement and speed of these fishes is based on their shape and body part (fin) use to move in the water. The motion of fins or bodies can provide more flexible maneuverability. The robotic fish systems have wide-range of applications in many areas: marine sourcing, seabed charting, environmental assessments, monitoring, and sea exploring.

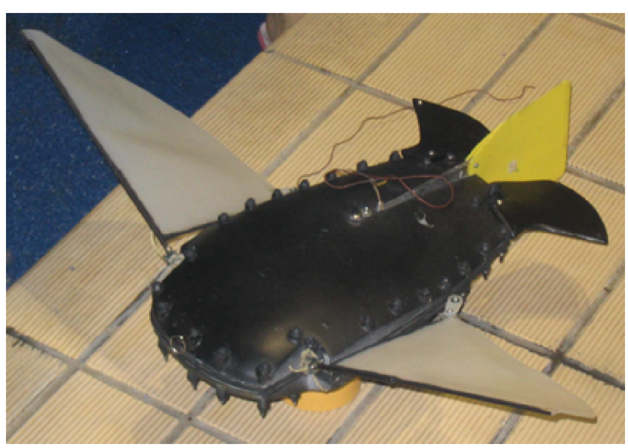


Figure 1.1: Example Of A Stingray Robot

1.2 Problem Statement

Similar to the conventional Autonomous Underwater Vehicles (AUVs), these robotic fishes is developed as a replacement for human. For the time being, human is required in order to explore in the deep sea. Diving into deep will expose human with high risk of danger - high water pressure and dangerous species. Human also can go underwater in certain amount of time due to certain limitation – oxygen and pressure. Also, some country explore and doing research underwater for military purpose. For all these reasons, an underwater vehicle is developing as a replacement for manpower.

1.3 Project Objectives

- To build a low cost robot that can move like stingray in the water.
- To design the mechanical and electrical structure and to construct a stingray robot.

1.4 Scope of Project

In order to achieve the objectives of the project, literature study on stingray's characteristic which includes the fin motion, the stingray movement and shape are done. Research on the fin motion is investigated to get the detail on how the robot will go forward. The maneuver and shape of the stingray is also being investigated and studied. For electrical and mechanical part, the details are referred from the manufacturer references. With deep research and study, an electrical circuit is constructed to make sure the robot can maneuver autonomously and the robot body is designed to make sure it can operate underwater.

CHAPTER 2

LITERATURE REVIEW

2.1 Characteristic

‘Over the past two decades, the interests in robotic fishes have experienced an increasing trend. In addition to works from active and prominent groups in the international biomimetics community on bio-inspired aquatic robots, recent research and development works on fish robotics by the team in Nanyang Technological University (NTU) will be presented in the paper’ [1].

There‘re several type of swimming mode. This mode is classified by the shape of the fin. Figure 2.1 show the type of mode for fish. Rajiform mode is found in fish such as rays, skates, and mantas, whose swimming has been likened to the flight of birds. The amplitude of the undulations increases from the anterior part to the fin apex and then tapers again toward the posterior. Figure 2.2 show the manta ray locomotion. The fins may also be flapped up and down. Manta ray of cartilaginous fish is one kind of the largest fish in the ocean, whose swimming mode is Rajiform mode. When the movements of the two fins are same, the manta ray swims forward. When the movements of the two fins are different, the swimming direction will change. The swimming speed is usually slow, but the manta ray can swim at high speed and sometimes leaps out of the water. The rear two fifths of the body are used to control vertical movements and perform somersaults.

Flexible fin can be divided into two parts: the relatively rigid basal part which is the first third part nearest to the body and the relatively flexible distal part. When the basal part is moving upward, the distal part may point down under the resistance of water and vice versa. [2]. In Brower's analysis, the profile of swimming motion is captured every 0.15 seconds. With 14 profiles captured in total, it is approximate that a total of 2.1 seconds is required to complete one flapping motion. Hence, the frequency of the flapping motion is approximately 0.5Hz [6].

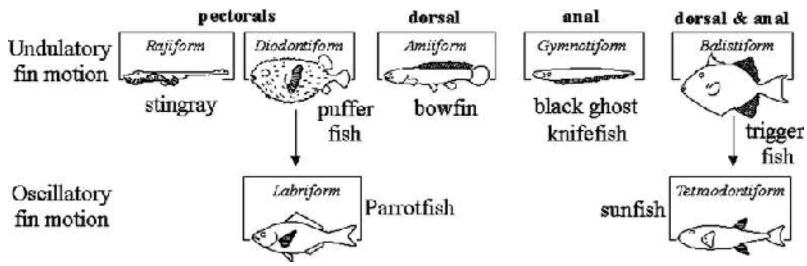


Figure 2.1: Scheme of Median and/or Paired Fin Locomotion

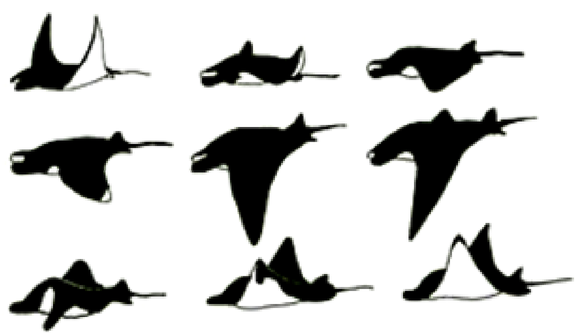


Figure 2.2: Klausewitz's Illustration of Manta Ray Locomotion

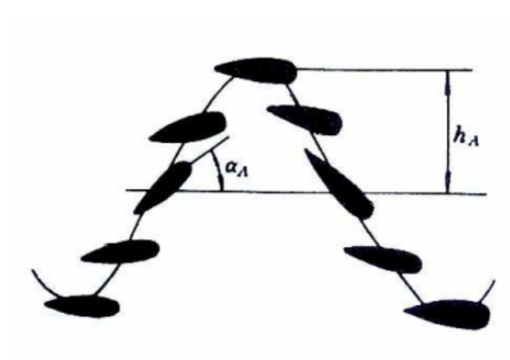


Figure 2.3: The Simplified Model of Fin Motion

2.2 Robot Development

Research and development in the area of fish robot has become popular in recent years. Fish have high efficiency, maneuverability, and lower noise than most of the current marine robots. The robotic fish is a combination of bio-mechanic and engineering technology.

2.2.1 A micro biomimetic manta ray robot fish actuated by SMA

A micro biomimetic manta ray robot fish actuated by SMA by Zhenlong Wang, Yangwei Wang, Jian Li, Guanrong Hang is an example of robot that use SMA (shape memory alloy). This method is easy to use, low-cost, light-weight and no noise compare to motors. SMA also has low operational voltage and long life but low in efficiency. This type of material has widely use in robotic field. Many robots use this material as wing, grip, robot hand, deformable robot, lobster robot, and robot fish.

SMA is a material that actuated by electric current. When heated from low temperature martensite to high temperature austenite, SMAs will return to their predetermined shape and produce the activation, which is known as reverse transformation. When cooled from austenite to martensite, SMAs undergo a martensite transformation and will return to their initial state by bias stress. The SMA operational frequency can be increased to over 2 Hz, which is high enough to simulate the bending movements of the fin.

The prototype of the robot is 243 mm in length (with a 110 mm caudal fin), 220 mm in width (with a 67 mm body), 66 mm in height and 354 g in weigh. Latex membrane (0.2 mm thick) is use as the fin surface. TiNi (50.2 at.% Ni) SMA wires with 0.2 mm diameter are employed. In biomimetic fin 1 and 2, the length of every SMA wires is 70 mm. The elastic substrate of biomimetic fin 1 and 2 is made of polyvinyl chloride (PVC) sheet with a thickness of 0.25 mm. Comparing with biomimetic fin, flexible fin does not include the SMA. The structure of the biomimetic fin is shown in Figure 2.5. A 11.1 V, 1500 mAh, 12 C Lithium polymer rechargeable battery is used as the robot power source. 111.8 g balance weight is placed under the power source to stabilize the robot underwater. With this balance weight, the robot can float in the water with a very small part of the dorsal cover out of water. With more balance weight of 2.3 g, the robot would submerge into the water completely. A design of low net buoyancy would make it convenient for the appending of static diving systems such as ballast tanks or dynamic diving systems such as fins. Figure 2.4 shows the design of the robot.

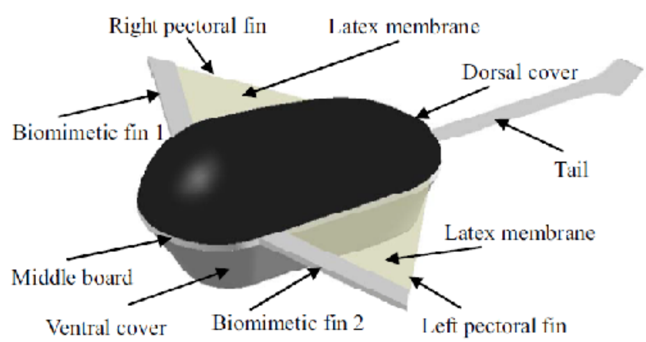


Figure 2.4: Micro Robot Design

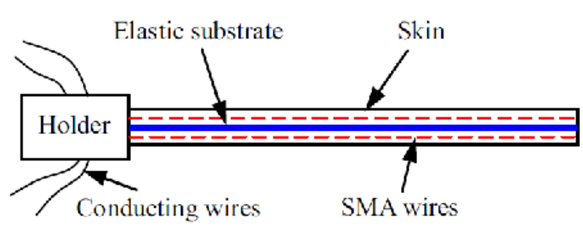


Figure 2.5: The Structure of Biomimetic Fin

Radio frequency remote control module is used for robot control employed. The control module is based on a PIC16F877A MCU. MOSFET is connected to prevent overheat that can damage the SMA. High current (up to 9 A at 28 V) used by the SMA to actuate can cause overheat. Figure 2.6 shows the architecture of the control system. Pulse generated by the microcontroller is applied to the SMA (fin ray) and the sequence of the pulse is shown in Figure 2.7. The pulse sequence 1 is for upward flap of the fin while the other is for downward flap with the width of t_{on} = 80ms while t_{int} = 700ms. The speed and the amplitude of the robot can be increase by increasing the pulse width. The robot turning motion is occurred when only a single fin is flapping while the other remains static. The turning angle can be change by adjusting the flapping amplitude and frequency [2].

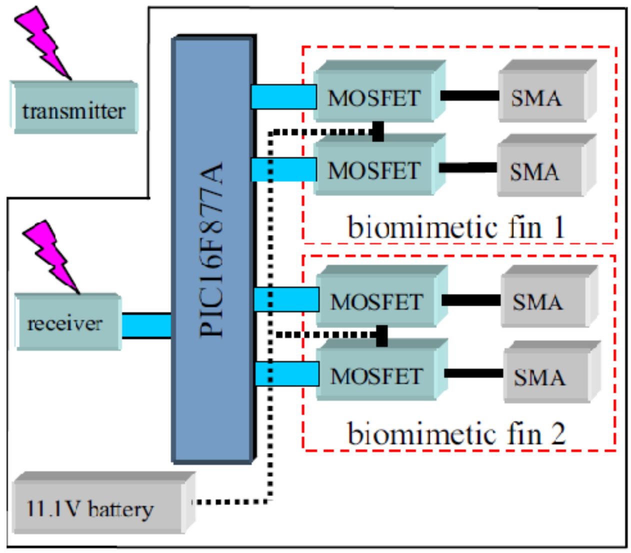


Figure 2.6: Control System Design

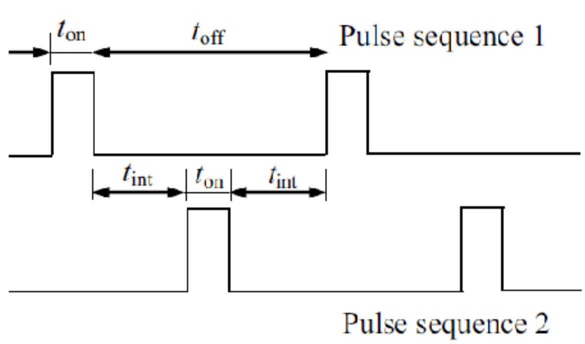


Figure 2.7: Pulse Sequence for Single Fin

2.2.2 Development of a Rajiform Swimming Robot using Ionic Polymer Artificial Muscles

Mimetic Control Research Center, Japan has developed a robot using Ionic Polymer - Metal Composite (IPMC) method as their robot element. The IMPC consists of an ion-exchange membrane whose surface is plated by thin rare metal layers. When voltage is applied across the electrodes, the hydrated cations move toward the anode. This water movement causes the swelling of the anode side of the ionic polymer therefore the bending moment is generated. The structure of the IMPC is shown in Figure 2.8. The IMPC is made from Nafion N-117 membrane (DuPont) through five times gold plating process. The size of the each IPMC is 5[mm] × 50[mm]. Thickness is about 0.2 [mm]. They used Na+ ion as its counter ion because IPMC doped Na+ exhibits quick response.

Eight IPMCs which is clamped by the acrylic support with copper electrodes is used for the fin ray. A thin polyethylene film is used as the fin surface. The IPMCs were put into the slit of the film as shown in Figure 2.9. The thickness of the film is about 12[μm], which does not inhibit the motion. The entire size of the fin is about 75[mm] × 45[mm]. This robot use a microcontroller system called *C-CHIP* whose size is only 30[mm] × 40[mm]. It has been developed at Bio-Mimetic Control Research Center, RIKEN and Aichi Institute of Technology.

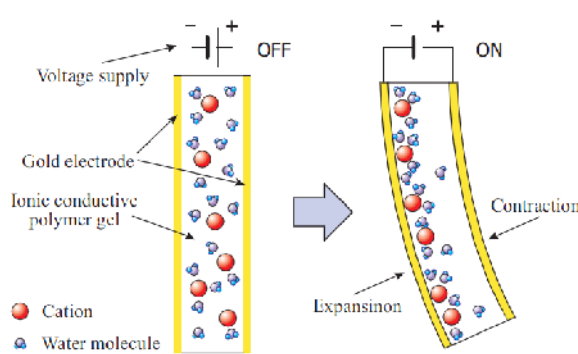


Figure 2.8: Illustrations of the Deformation Mechanics of IPMC

A linear amplifier using two transistors and an OP amp is used to prevent plating damage cause by unnecessary current. This current is the result of water electrolysis causes by high voltage. Because the electrical impedance of IPMC is capacitive, lower current flows during driving at lower frequencies. Taking these into account, an estimation of the flowing current of an IPMC is at most a few hundreds milliamperes. The amplifier maximum output current and voltage is about ±500mA and ±2.5V respectively [3].

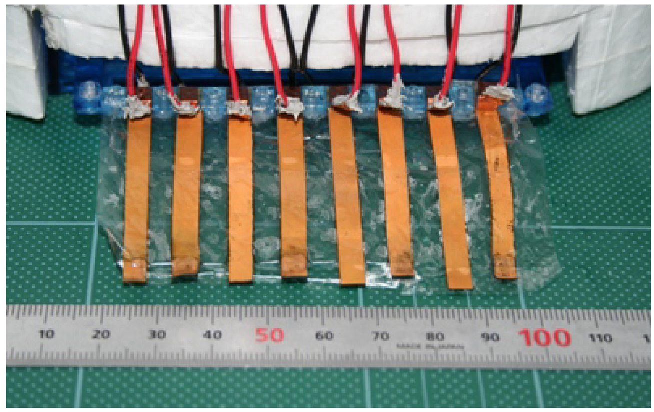


Figure 2.9: Developed Fins with Eight IPMCs

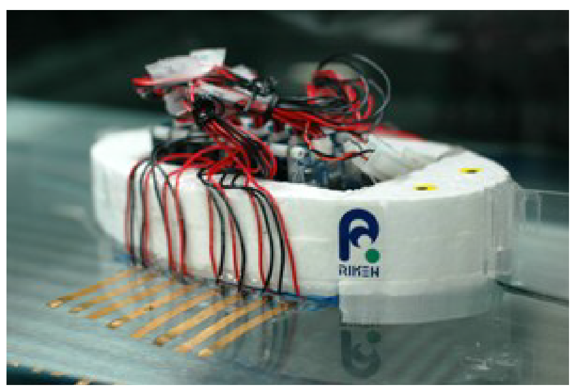
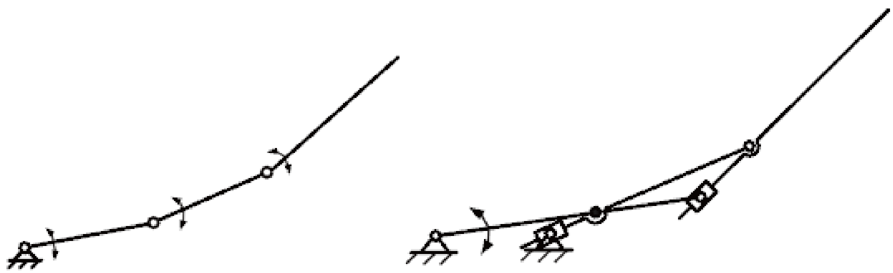


Figure 2.10: The Robot Overview

2.2.3 Design and Optimization of a Robotic Fish Mimicking Cow-nosed Ray

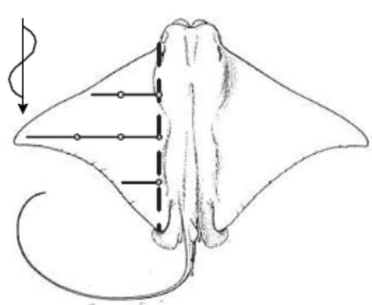
Licheng Zheng, Shusheng Bi, Yueri Cai, and Chuanmeng Niu has Design and Optimize a Robotic Fish Mimicking Cow-nosed Ray. The robot use 6 servo motors, 3 motors on each side of fin to move the robot. The robot is designed similar to cow-nosed ray in nature. Mould made of plexiglass is manufactured for flexible pectoral fins. Mechanism with three revolution joints as shown in Figure 2.11(a) can be used as a fin ray based on the locomotion. The joint require 3 actuating motors which make the fin ray heavy and difficult to control. To overcome this disadvantage, a rocker-slide mechanism as shown in Figure 2.11(b) is designed which use only one motor. All the link rods are made of duralumin except the distal rod, which is made of carbon fiber to provide elasticity.



(a) (b)

Figure 2.11: (a) Mechanism with three revolution joints. (b) Two stage rocker-slide mechanism. Where arrows are need actuators.

The pectoral fin of cow-nosed ray is approximate to a triangle, so the joint number is different for different fin rays. There are 2, 3, 1 joints for the fin rays from front to back respectively, as shown in Figure 2.12.



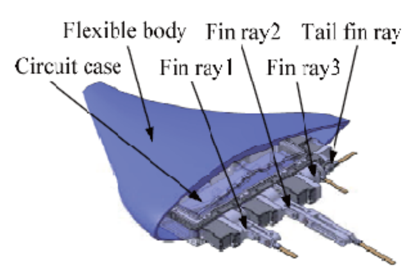


Figure 2.12: Fin's Joint Structure Figure 2.13: Fin Structure

In order to prevent the electrical devices from damage, flexible skin made of silicon rubber is used because of its waterproof ability. Moreover, the major components, like servo motors and circuits, are also designed to be waterproof. Thus the damage can be avoided even if the flexible skin fails to be waterproof. Servo motors are sealed by glyd rings, seal covers and the base parts [4].

2.2.4 Better Endurance and Load Capacity an Improved Design of ROMAN-II

Chunlin Zhou, Kin-Huat Low from School of Mechanical and Aerospace Engineering, Nanyang Technological University have design a manta ray robot called Roman-II. Roman-II is an improved design of Roman-I. Roman-I have too many joint and linkage on the ray which requires much energy to drive. This will significantly reduce the swimming efficiency. Elastic material is used on Roman-II to introduce compliance capability in the fin motion. A fin membrane in silicon rubber sheet is us as the fin surface resulting motion control becomes less complex and consumption of energy could also be reduced. Figure 2.14 shows Roman-II mechanical design

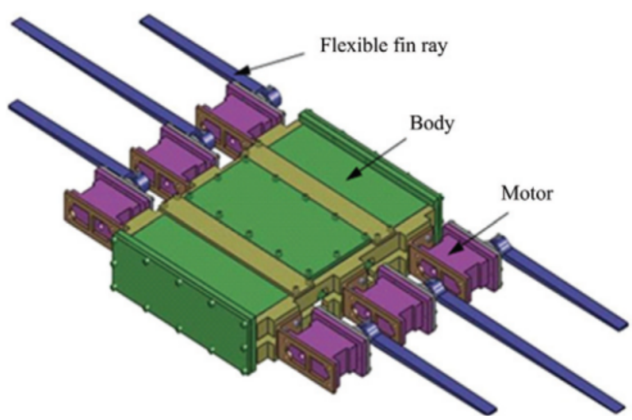


Figure 2.14: Roman-II Mechanical Design

The flapping of Roman-II fins of upstroke only takes about half time of down stroke for one full flapping cycle. Figure 2.15 show the harmonic gait of fin flapping. This robot also can perform a turning motion by generating bigger thrust on one side of flapping fin. By doing this, the robot will turn towards another side. The thrust control can be achieved by reducing the oscillation frequency and/or amplitude. The pivot turning occurs when fin on one side is performing forward swimming, whereas the fin in another side is performing backward swimming. During gliding motion, the robot in the present work makes use of small changes in its buoyancy together with the help of two sided fins to convert vertical motion to horizontal [6]. Figure 2.16 shows the fin position for gliding motion.

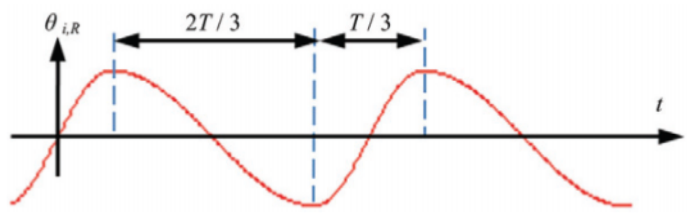


Figure 2.15: Control signals for a fin ray

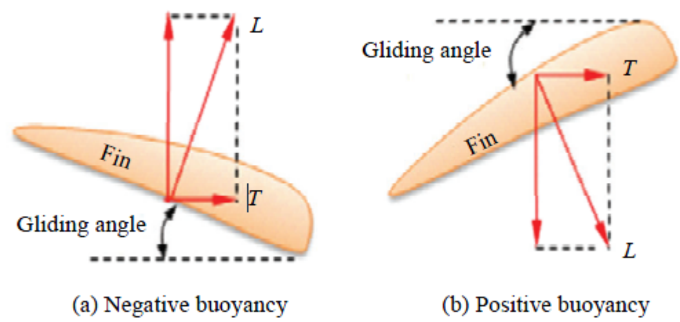


Figure 2.16: Fin Position for Gliding Motion

2.3 Buoyancy System

Archimedes stated that "any object, wholly or partially immersed in a fluid, is buoyed up by a force equal to the weight of the fluid displaced by the object'. When an object submerged in the fluid, experiences greater pressure at the bottom is greater than at the top. An object tends to sink when its density is greater than the fluid in which it is submerged and afloat if the object less dense than the fluid. As for fish, their gas bladder has flexible walls that contract or expand according to the surrounding pressure. The bladder has a gas gland that can introduce oxygen to the bladder to increase its volume and thus increase buoyancy. To reduce buoyancy, gases are released from the bladder into the blood stream and then expelled into the water via the gills [11]. Buoyancy system for underwater vehicle or robotic fish is the main criteria in developing fully functional robot.

In many robot development, air or gas is use to reduce the density of robot. The buoyancy system of Roman-I is using air bladder for that purpose. When the air bladder expand, the water in cylindrical ballast is expels out. But the developer found that the system is not effective as problems occur when operating the robot underwater. The problems are when the pressure in the air bladder as at certain value, the bladder cannot become larger. The air pump will not work well due to the vacuum in the water tight container. As the robot dives, the water compresses the bladder, which then increases the burden of the air pump. Instead of using air pump, the water pump is used to overcome these problems. This improved system is implemented on Roman-II with additional water pressure sensor to detect the depth, closed-loop buoyancy control and depth control [6]. Figure 2.17 shows buoyancy system for Roman-I and Roman-II.

A knife fish robot build by Nanyang Technology University use a buoyancy system based on the fish system. An opened end tank with 2 pistons that retract and extend using lead screws is use for the system as shown in Figure 2.18. In order to maintain the robot horizontal angel the piston on both sides is adjusted. If the right side of the buoyancy tank is higher than the left side, the piston on the right side will retract and this will bring the buoyancy tank to a horizontal angle. In the case that the right piston is fully retracted, the left piston will extend and again bring the buoyancy tube to a horizontal angle [11].

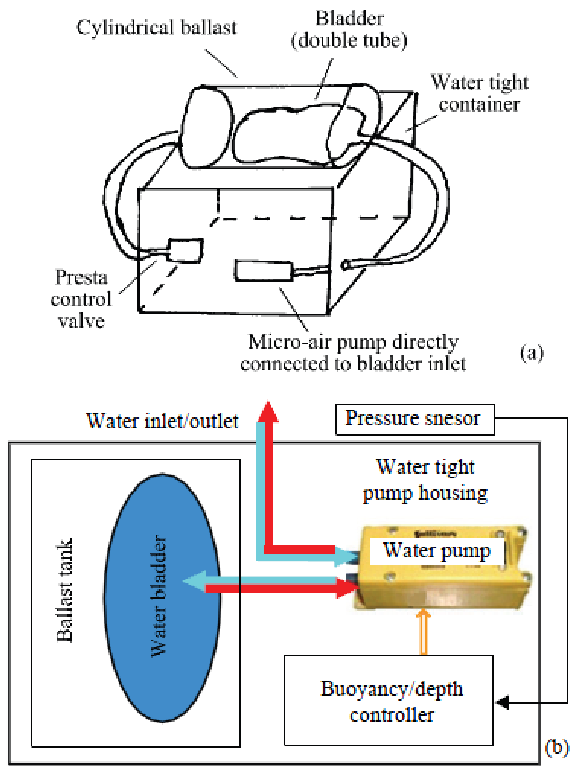


Figure 2.17: Buoyancy System for (a) Roman-I and (b) Roman-II

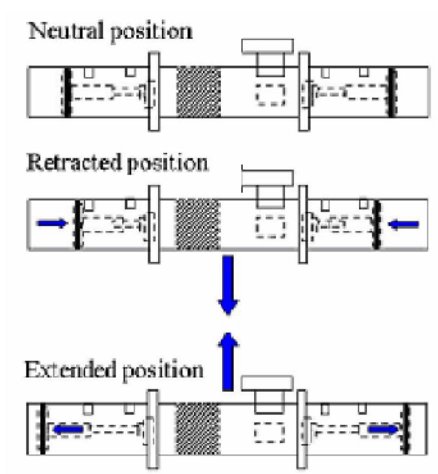


Figure 2.18: Knife Fish Robot Buoyancy System